5-2019

3D Printing a Microfluidic Chip Capable of Droplet Emulsion Using NinjaFlex Filament

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ACKNOWLEDGMENTS

I would like to thank Dr. Steve Tung with the University of Arkansas for providing the resources and guidance to make this experiment possible. I would also like to thank the University of Arkansas Department of Mechanical Engineering and Honors College for providing the facilities and equipment to conduct this research. Lastly, I would like to thank Dr. Larry Roe and Dr. Rick Couvillion for serving as members of my thesis committee and giving me invaluable advice and insight into ways to improve this summary of my work.

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ABSTRACT

This paper details an investigation into methods and designs of 3D printing a microfluidic system capable of droplet emulsion using NinjaFlex filament. The specific field in which this paper's experiment is rooted is dubbed "BioMEMS," short for bio microelectromechanical systems. One prominent research area in BioMEMS is developing a "lab on a chip." Essentially, the goal is to miniaturize common lab processes to the micro scale, rendering it possible to include these processes in a small chip. Reducing necessary sample sizes, shortening the reaction times of lab processes, and increasing mobility of lab processes can all be realized through microfluidic designs.

This experiment specifically investigates the ways in which micro droplets can be generated in a chip 3D printed from NinjaFlex filament. Printing in NinjaFlex came with a few challenges, including blocked micro channels from unintentionally extruded material and an unreliable bond with glass. However, at a set of optimum print parameters and utilizing a specially tailored design, it was found that NinjaFlex could reliably be used to 3D print a microfluidic system capable of droplet emulsion. For the final design iteration described in this paper, a oil side pressure of 2.5 psig and a water side flow rate of 25 microliters/minute induced uniformly sized droplets (about 1100 microns in diameter) at a regular time interval of about one every four seconds. In future research, it would be useful to have more control over the oil side flow rate. Also, there is room to optimize the current chip design by adding flexible diaphragms or reducing the diameter of the micro channels, thus giving the user more control over the droplet size and interval of formation.

NOMENCLATURE

i	percent infill, unitless
T_e	extrusion temperature, degrees C
v_e	extruder tip velocity while extruding, mm/s
v_t	extruder tip velocity while traveling, mm/s
h	layer height, mm
E_{NF}	modulus of elasticity, NinjaFlex
E_S	modulus of elasticity, rubber silicon
$\dot{V}$	volumetric flow rate, $\mu L/min$
Ca	critical capillary number, unitless
η	viscosity of continuous phase, m^2/s
v	velocity of flow, m/s
γ	interfacial tension between phases, m^3/s^2

1. INTRODUCTION

1.1 3D printing

3D printing designs and technologies, while seemingly new, have been in development over the past 40 years [1]. 3D printing was originally rooted in stereolithography, which uses UV light to solidify a liquid polymer to a desired shape [1]. This, however, came with issues such as warping in the structures along with inherent stresses from the solidification process [1]. Jumping forward 40 years, open source technology and software has allowed 3D printing to become a more viable solution to engineering projects, whether on small or large scales. Falling prices of 3D printers and higher accuracy have also helped solidify 3D printing as a serious contender to milling/molding parts. Currently, 3D printing involves extruding various materials from a nozzle at various rates in layers. 3D printing has strong potential in mechanical/biological engineering fields because of the ability to fabricate a part in varying materials relatively easily.

1.2 BioMEMS and the "Lab on a Chip"

In the field of biomedical/biological engineering, an emerging topic of study is seeking to utilize 3D printing fabrication. This special topic is called "BioMEMS," short for biomedical microelectromechanical systems. The main pursuit in this field is to miniaturize certain biological testing processes that already exist. Examples of such processes include modeling drug delivery and analyzing different biological solutions [2]. These processes utilize systems of very small channels, which for this paper's purposes, can be considered to be miniaturized piping systems, to transport biological solutions. BioMEMS is also referred to as "lab on a chip" because of the desire to retain all functionality of lab processes with the convenience of only needing a small chip. In most cases, the scale being dealt with is anywhere from 10-1000 μm. There are obvious advantages to shrinking such technology, including increased mobility and ergonomics of testing apparatuses. In addition, reducing the size of the apparatus also reduces the amount of reactant and reagent needed in the biological processes being tested, resulting in faster reaction times and shorter wait periods. Traditional methods of fabricating a "lab on a chip" include stereolithography, film deposition, etching, and bonding [2]. All of these processes are relatively time consuming and more complex when compared to 3D printing. Because of this, developing a way to 3D print a "lab on a chip" would increase cost and time efficiency greatly.

1.3 Mechanical Systems in BioMEMS: The Flexible Diaphragm

A common question might be, "Where do mechanical systems come into play with a micro-scale biological testing apparatus?" In the development of the lab on a chip, special attention needs to be given to achieving a desired flow rate of the biological solution. Fluid flow is brought about through either generating a pressure gradient or using a flexible diaphragm along the length of the microfluidic channel, which expands and contracts at a certain frequency to achieve the desired flow rate. Depending on the material and the thickness of the diaphragm, varying pressures and frequencies would be needed to achieve a certain flow rate. As a side note, these diaphragms can also be used either to modify the width of the microchannel, or as check valves if the pressure is increased beyond a certain threshold (enough to cause the displacement of the diaphragm to be equal to the diameter of the microfluidic channel).

1.4 Emulsion Droplets in Microfluidics

This experiment specifically seeks to determine the printing constraints and microchip design that facilitates microfluidic droplet separation. More specifically, these separated droplets are referred to as "emulsion droplets." The process for generating the emulsion droplets is fairly simple: if two streams oil are introduced to a stream of water-based biological solution from both sides, the solution will dissociate from the oil and form droplets within the outbound stream. The figure below is representative of this process. In this image, the biological solution is comprised of hydrogel beads, cells, and some reagent. The solution is combined where the three inlets meet. As it passes the two oil inlets, the solution is dissociated into droplets. Each of these droplets can be analyzed individually depending on what lab process is being tested. A figure of the water droplet emulsion is given below.

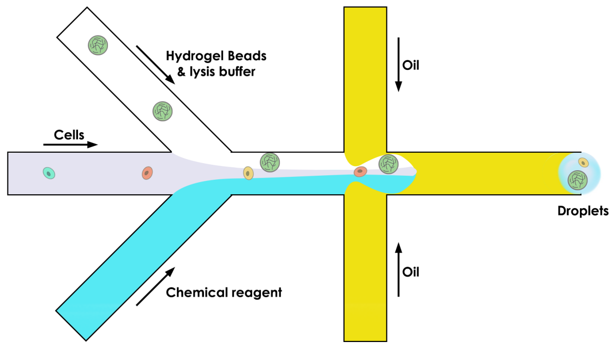

Figure 1.4.1: Illustration of the droplet emulsion process [3].

1.5 Applications of Droplet Emulsification

There are substantial applications that could benefit from 3D printed microfluidic droplet separators. It has been demonstrated that glucose concentration could be measured using droplet separation from a wide variety of biological fluids including saliva, serum, and plasma [4]. In another experiment, blood was monitored for the time-dependent clotting behavior, and results obtained from the microfluidic apparatus matched those acquired using traditional lab methods [4]. Other applications include chemical detection for food safety and new drug discovery in the pharmaceutical industry [4].

1.6 NinjaFlex as a Fabrication Option

Developing a reliable method and design for 3D printing a microfluidic system in NinjaFlex would have significant advantages over traditional methods of fabricating such technology. Traditional methods include a molding process using PDMS and 3D printing in ABS plastic [4]. The molding process is very time consuming and complex when compared to 3D printing [4]. This is because fabrication in PDMS involves two steps: molding the PDMS into the desired shape (and waiting for it to cure), and bonding the PDMS to some sort of substrate (normally glass) [4]. 3D printing eliminates the need for bonding to a substrate in a separate step because the 3D print can be done directly onto the glass substrate surface, or the part itself can have a base built from 3D printed material. 3D printing in NinjaFlex rather than ABS has one inherent advantage for the specific application of generating microfluidic systems. NinjaFlex has a Young's modulus of 12 MPa [5], while that of ABS is 2.05 GPa [6]. This results in ABS having a stiffness roughly 170 times that of NinjaFlex. This reduction in stiffness is advantageous for fabrication of microfluidic systems because these systems may need actuators that need to flex and bend to generate fluid flow. Much less pressure is needed to generate a deflection in NinjaFlex than to generate that same deflection in a geometrically similar sample of ABS.

2. OBJECTIVE

The objective of this project is to determine the efficacy of using different 3D printing methods to create a microfluidic chip capable of droplet emulsification. The material being tested is NinjaFlex, and the characteristics being tested include flow rate through the chip, quality of droplet separation, and size of the droplets. If needed, the original part file will be modified to achieve a reasonable flow rate.

3. THEORY

3.1 Optimal Printing Parameters

Before any droplet separation could be tested, developing and printing the microfluidic chip needed to be accomplished. This presents a serious challenge, as 3D printing resolution sometimes needed to be as accurate as 50 μm (or less) in microfluidic applications. The process of achieving such high resolution was different depending on what material was being printed. In the case of the NinjaFlex, the desired resolution could be achieved by adjusting the print settings. More specifically, the percent infill, extrusion temperature, extruder tip velocity, and layer height were altered to increase resolution. Through a trial and error process (described in the experimental setup section), the best print settings were found. These are listed below.

$$i = 95\%$$

$$T_e = 250 \deg C$$

$$V_e = 10\ mm/s$$

$$V_t = 200\ mm/s$$

$$h = .10\ mm$$

3.2 Issue of Undesirable Toolpaths

Another challenge was ensuring that the toolpath of the 3D printing nozzle does not pass over the microfluidic channel, unintentionally blocking the microchannel. The code, which dictates the path of the extruder, is generated by the chosen 3D printing software. It cannot be specially tailored for parts easily. If the tool must travel over the microchannel, material should not be extruded into the microchannel. Because of the design of the microchannel, there was no way to alter the toolpath such that it did not pass over at least one microchannel. One way to overcome this is to increase the extruder tip velocity when it is not extruding.

3.3 Ensuring Droplet Separation in Micro Channel

Once the quality of the print was acceptable, droplet formation needed to be tested. The formation of droplets depends on the a dimensionless term called the "critical capillary number" [4]. As long as the critical capillary number is relatively high, droplet formation will occur. An expression for determining the critical capillary number is given below.

$$Ca = \frac{\eta v}{\gamma}$$

In this equation, η represents the viscosity of the continuous phase of liquid (in this case, oil), v is the flow velocity, and γ represents the interfacial tension between the two phases (water and oil.) One thing of note is that the critical capillary number is highly variable between different microfluidic systems. Flow velocity will not vary much and the interfacial tension will be constant if the geometry of the chip and the fluids are kept constant. Therefore, to achieve a high capillary number, the viscosity of the continuous phase needs to be relatively high, which is why oil is often used as the continuous phase.

4. EXPERIMENTAL SET UP

4.1 Equipment

The following equipment was used. See Appendix for equipment details.

- MakerBot Replicator 2 3D printer
- SolidWorks
- NinjaFlex printing material
- Glass chip
- MakerBot Print software

- Tape
- Microscope
- Syringe Pump
- Z-axis adjustable support stand
- 1/8 in. inner diameter tubing (2 ft)
- 1/32 in. inner diameter tubing (4 ft)
- 3 micro piping connectors
- Micro T junction
- Nitrogen tank (pressure source)
- 3 mL syringe
- 30 cc syringe
- Syringe nozzle (1.6 mm ID)
- Vegetable oil (canola oil)
- Water
- Dremel Tool
- Green food dye

4.2 Design and Fabrication Procedure

The following procedure was used for each iteration of design and fabrication of the 3D printed chips.

1. Part was developed in Solidworks with direct consultation from Dr. Steve Tung.

2. File was loaded into MakerBot software and print parameters were chosen based on previous research on printing NinjaFlex [7] (note: these parameters were changed iteratively as described in the Data and Results).
3. File compatible with 3D printer (.x3g file type) was generated using MakerBot software.
4. Glass chip was placed in approximate position where print would be generated according to the file generated by the MakerBot software. Glass chip was taped down to ensure it did not move during print process.
5. The preheat setting on the MakerBot was set to 250 C and the NinjaFlex filament was loaded into the extruder. A small amount of filament was extruded to ensure the nozzle would not jam as soon as the print started.
6. Part file was loaded onto the MakerBot and print was generated.
7. Print was examined under microscope to observe the quality of the print (for example, whether the channels were blocked.)

Images of the 3D printing experimental setup are given below.

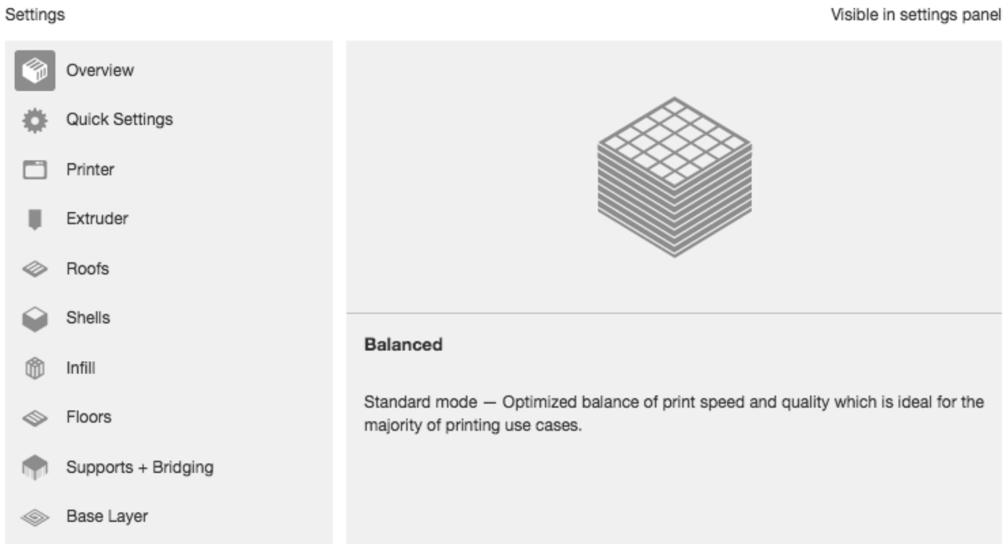

Figure 4.2.1: Print settings available for modification in the MakerBot print software.

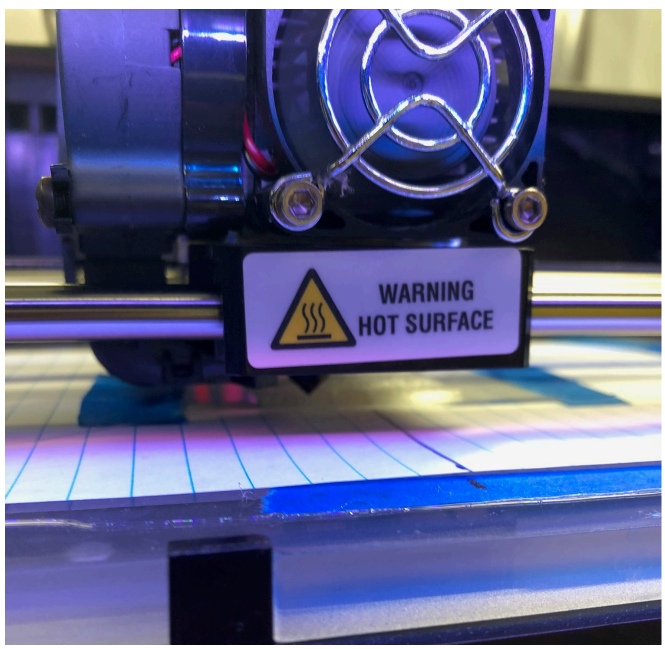

Figure 4.2.2: Glass chip secured onto build plate using tape.

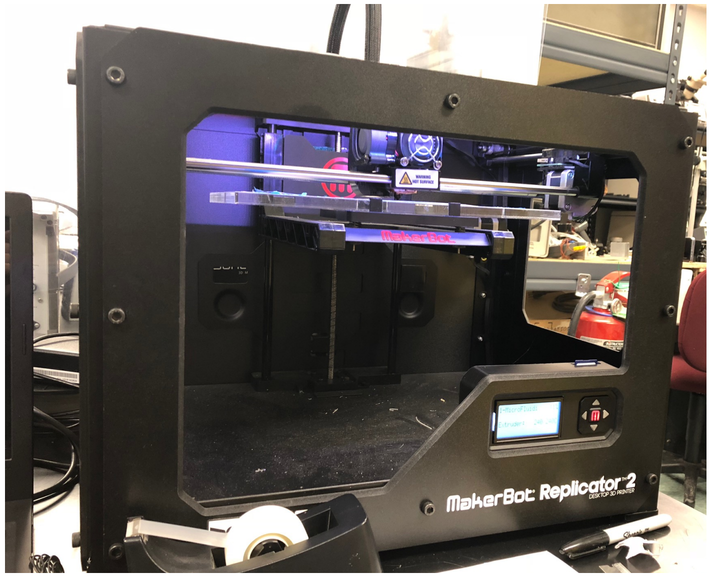

Figure 4.2.3: MakerBot Replicator 2 3D printer setup.

4.3 Droplet Emulsion Testing Procedure

The following procedure was used for testing whether the selected microchip had the capability of generating droplets.

1. Microfluidic piping connectors were inserted in the oil and water inlets of the final design.
2. 1/32 in tubing was connected to each of the piping connectors in the chip.
3. The water supply line was connected to the 3mL syringe.
4. The two oil supply lines were combined into one line through using a T-junction connector.
5. The water syringe was placed in the syringe pump, and the syringe pump was programmed to deliver 50 μL/min of water.

6. The oil supply line was connected to the 30cc syringe; this syringe was connected to a pressure source (nitrogen tank), which could be regulated using a pressure regulator.
7. The chip was placed in the adjustable support stand at a height such that the micro channels in the chip would be focused and in view of the microscope.
8. Both the syringe pump and the pressure source were turned on. The micro channels under the microscope were observed to see if droplet formation occurred.

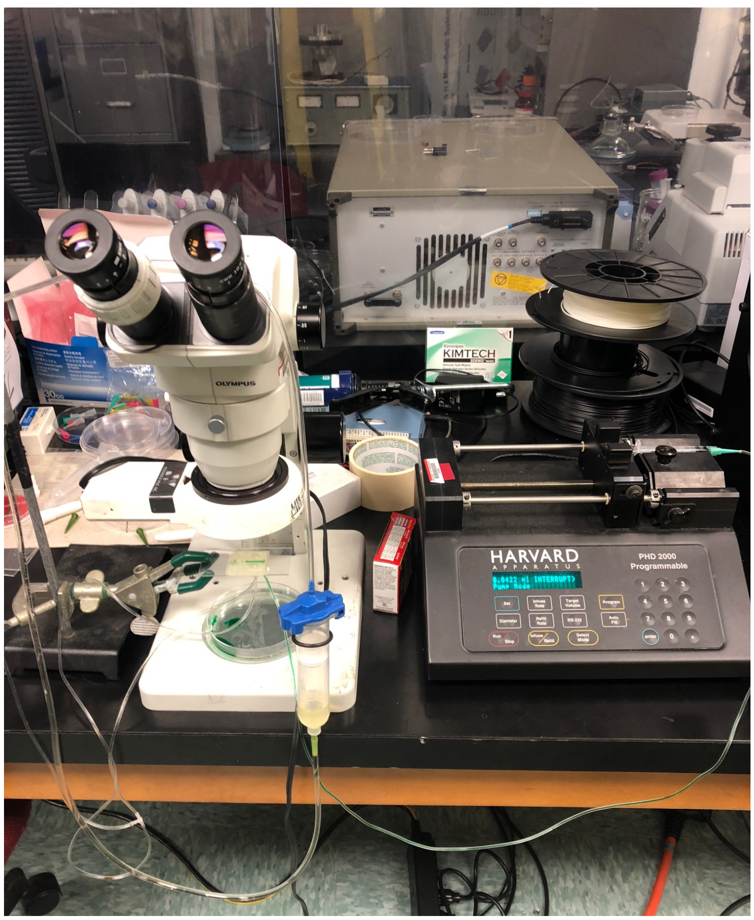

Figure 4.3.1: Droplet emulsification lab setup.

5. DATA AND RESULTS: 3D PRINTING

5.1 Design and Fabrication Approach

5.1.1 T-Junction Design

Originally, the design of the chip incorporated a T-junction for the oil to envelope the biological fluid. There was one inlet for the biological fluid, two inlets for the oil, and one outlet for the emulsion droplets. An image of the first iteration of the design is shown below.

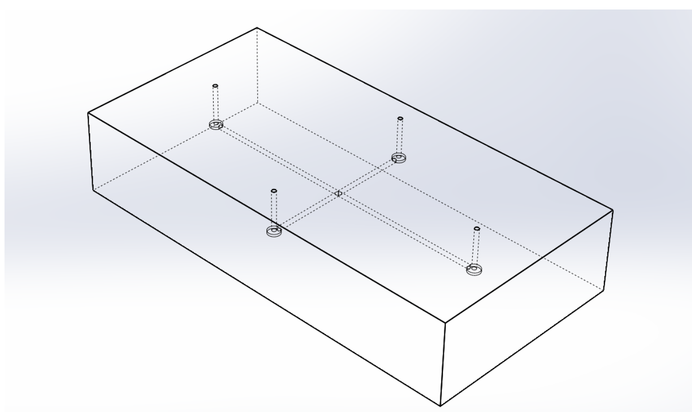

Figure 5.1.1a: T-Junction Solidworks design.

5.1.2 Angled Junction Version 1: Design and Results

The first design was not chosen for printing based on the desire to combine the two oil inlets into one. After consultation with Dr. Steve Tung, an alternate design was chosen for iteration on the MakerBot 3D printer. This design still included a junction, but the angles between the paths of the three inlet channels are reduced greatly. Also, there was only one oil inlet rather than two inlets. An image of the microfluidic chip is shown below.

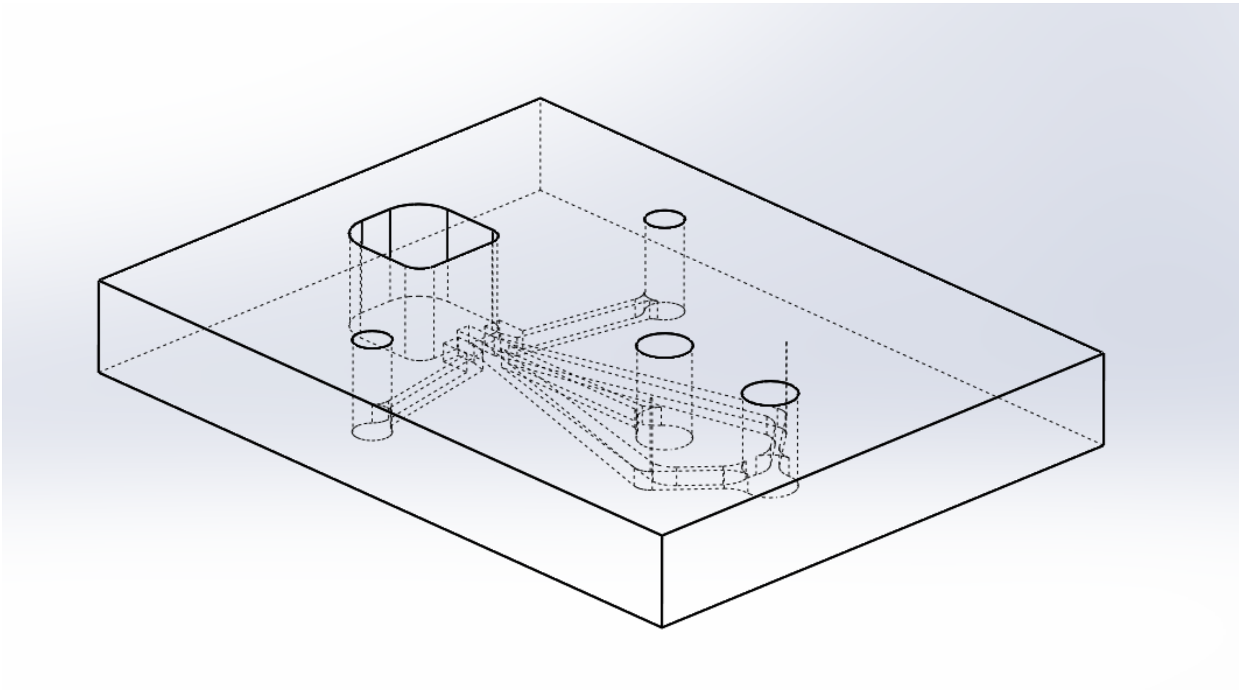

Figure 5.1.2a: Angled Junction Version 1 chip Solidworks part.

There were some concerns about some characteristics of the chip design. For example, there is a piece in the center which is surrounded by channels on all sides, which means that the extruder would have to pass over the channels to extrude the centerpiece. This would open the possibility for blockage of the micro channels, rendering the chip unusable. For the first print, the part was not modified in any way. The extruder temperature, taken directly from the previous research on NinjaFlex, was set to 220 C [7]. The percent infill, extrusion tip velocity (while both traveling and extruding), and layer height were set to 80%, 10 mm/s, and .14 mm respectively. The material was extruded onto a glass chip to ensure a good bond. Images of the first print are shown below.

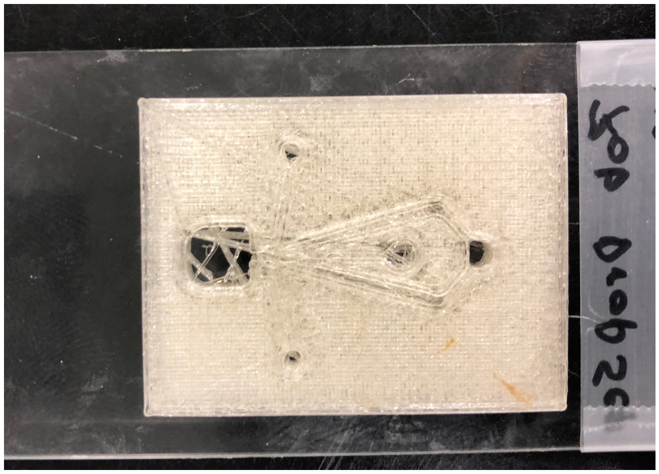

Figure 5.1.2b: Bottom view of first print of microchip.

As can be seen, there is some distortion in the print quality due to the default toolpath of the extruder. The outlet is completely blocked by extruded material. Also, the chip is much too thick; there is no advantage to having so much extra material overlaying the micro channels. Another issue is that the neither the micro channels nor the diaphragm is visible, so there is no easy was to know if those components have the necessary resolution. With respect to the 3D printer itself, it was noted that jams often occurred at this extruder temperature, T_e. Because of this, T_e was increased to 250 C. Jams occurred much less frequently, if at all, at this extruder temperature.

5.1.3 Resolution Test

After more consultation with Dr. Tung, it was decided that a resolution test would be conducted to see if the 3D printer was capable of generating the small diameter micro channels that were in the part file. To do this, a few layers of a small cross section of the part were printed to examine the quality of the channels. The print settings used in this iteration were the same as those in the previous iteration. An image of this print is given below.

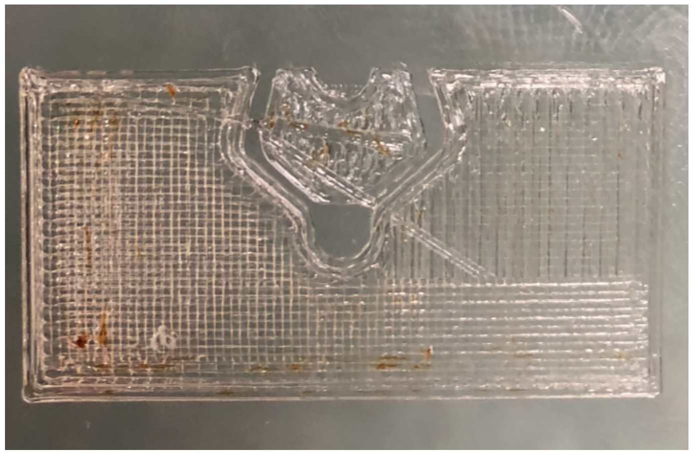

Figure 5.1.3a: Cross sectional print of the microfluidic chip to ensure resolution is acceptable for chip.

The resolution from this print is acceptable for a microfluidic system. However, the toolpath issue is realized in this iteration: the micro channels are blocked from material that should not have been extruded.

5.1.4 Angled Junction Version 2: Design and Results

With respect to design changes in the next iteration, the top of the chip was removed in the part file, leaving the channels viewable from above. Instead of a top composed of NinjaFlex, the microchip would be capped with a glass chip. An image of the part is given below.

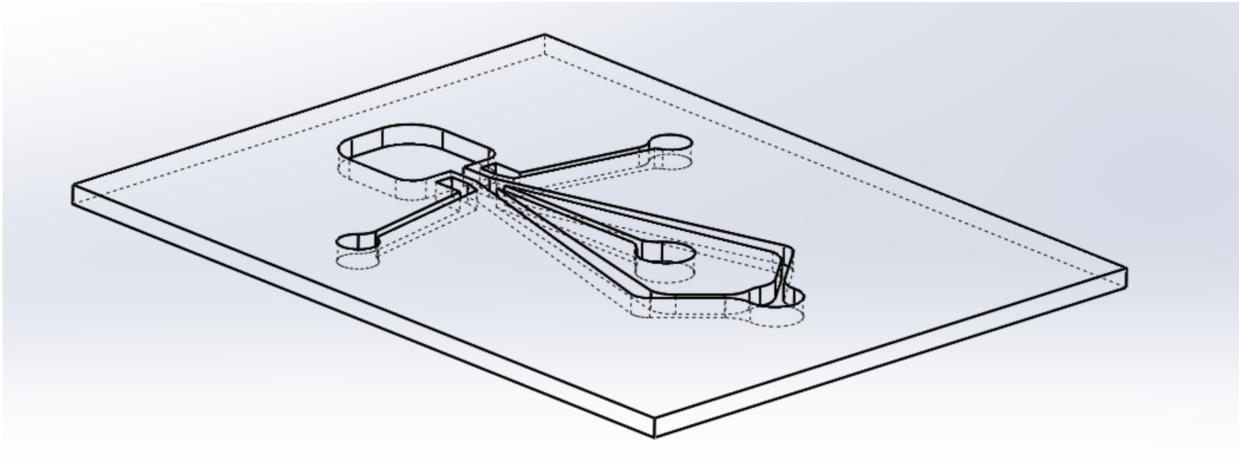

Figure 5.1.4a: Angled Junction Version 2 Solidworks part.

The new design was printed with the same settings as the first print except for the layer height, which was changed to .1 mm to improve resolution. An image of this print is given below.

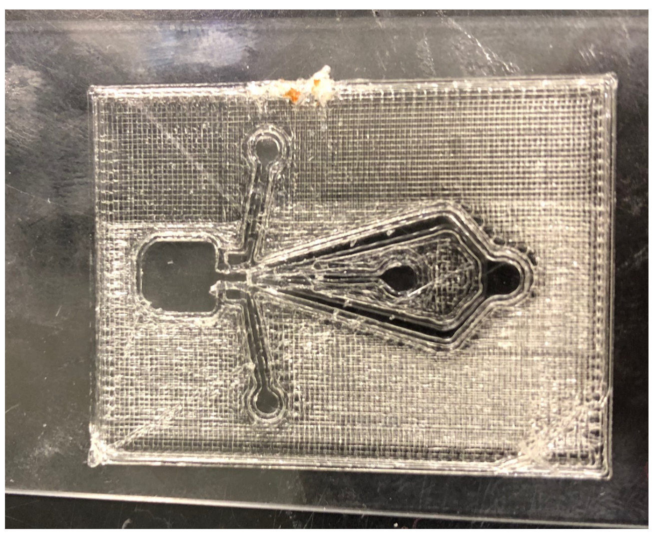

Figure 5.1.4b: Improved resolution achieved from reducing layer height.

The only issue with this print is the toolpath causing the channels to be blocked. Other than that, the chip has the required resolution to have a reasonable chance to generate droplets.

5.1.5 Troubleshooting Blocked Channels: Increasing Travel Speed

To combat this issue of the toolpath causing channels to be blocked, increasing the extruder speed v_t was attempted. The line of thinking behind this approach is that if the extruder moves more quickly when it is not extruding, less material will be deposited and, perhaps, the microchannel will not be blocked. In the next three print iterations, the extruder travel speed was increased from 10 mm/s to 100, 200, and 300 mm/s. Unfortunately, even at a 300 mm/s travel speed, the micro channels were still blocked. An image of the chip is shown below.

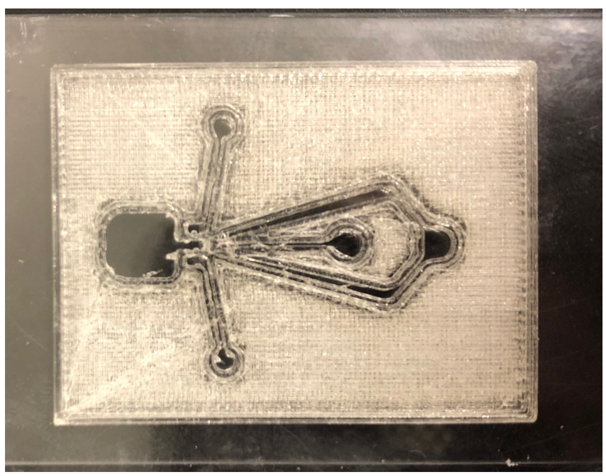

Figure 5.1.5a: Angled junction version 2 print with $v_t = 300\text{mm/s}$. Note that the junction is blocked completely.

5.1.6 Angled Junction Version 3: Design and Results

Because increasing extruder speed was unsuccessful, changing the design and the print pattern was the next possible solution. After further consultation with Dr. Steve Tung, the chip was modified further so as to increase simplicity and hopefully generate open channels. Rather than only have one inlet for the oil, two inlets were constructed on either side of the water inlet. Also, the width of the channels was increased by about 400 μm in the hope that the NinjaFlex would not block the channels as easily. Lastly, the diaphragms were removed from the chip in an attempt to increase the simplicity of the print. An image of the new design is given below.

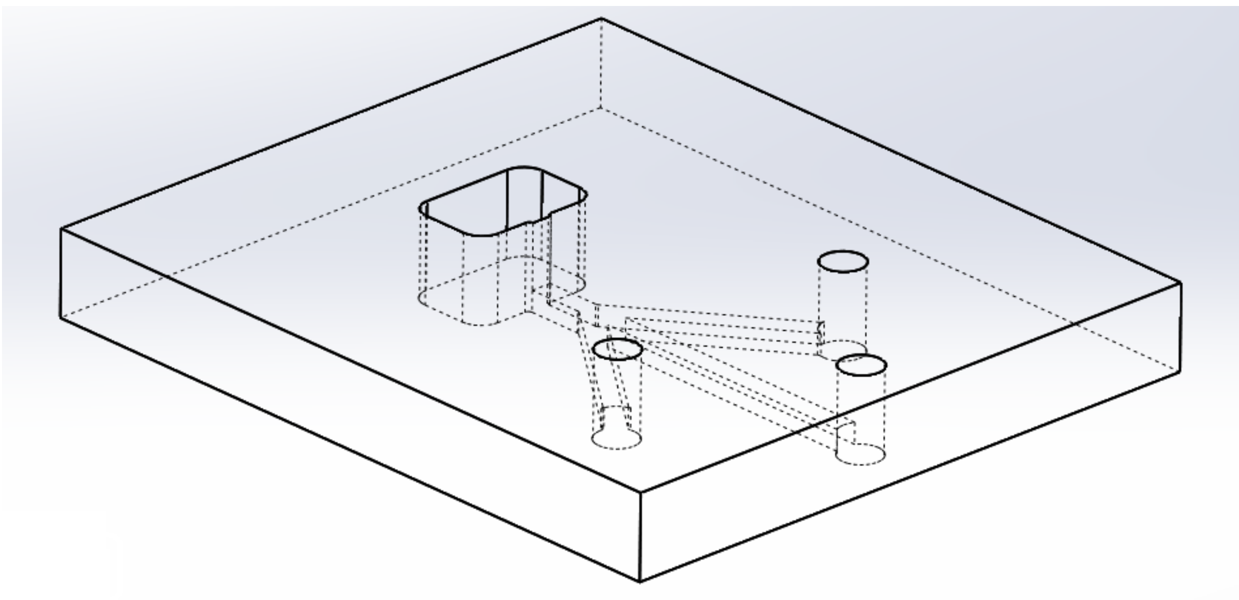

Figure 5.1.6a: Angled Junction Version 3 chip Solidworks part.

The print was done with i set to 95%, v_t set to 200 mm/s, and the rest of the print settings similar to the previous iteration. The print quality of this design was much better than that of the chip with only one oil inlet. An image of the print is given below.

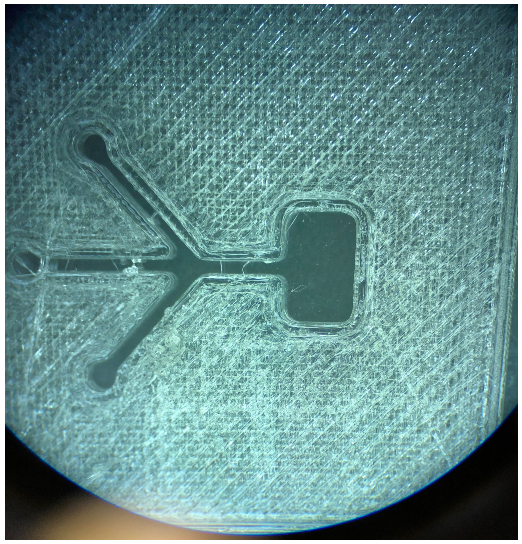

Figure 5.1.6b: Resolution achieved utilizing new design.

As can be seen, the water inlet on the far left still has some blockage. All other inlets are clear of blockage.

5.1.7 Investigating Infill Patterns in Relation to Toolpath

Since the Angled Junction Version 3 design would likely succeed in droplet separation, an iterative process was used to attempt to generate a print of this design with no blockages. To do this, the majority of infill patterns in the MakerBot print software were tested to see which option provided minimal blockage. The table below specifies the infill pattern and the results of the print.

Infill Pattern	Results
Linear	Water in blocked, others fine
Hexagonal	Water in blocked, others fine
Cat Fill	Water in blocked, others fine

Shark Fill	Water and oil in blocked
Donut Fill	All inlets blocked
Sunglasses Fill	Water in blocked
Hilbert Fill	Water in and outlet blocked
Diamond Fill	All inlets blocked

Table 5.1.7a: Infill patterns and observable results under microscope.

From these results, the pattern chosen for the final design print was the linear pattern. This pattern was chosen because it seems to have the same chance for success as the other fill patterns while being by far the simplest pattern.

5.1.8 Final Design Choices for Droplet Emulsification Testing

Two designs were chosen for the beginning the droplet emulsification testing. The first design is the Angled Junction Version 3 chip, and the other design is a modified version of this design. In the modified version, the top cap (made of NinjaFlex) will not be printed; rather, a glass chip was placed to cap the chip. This modification was made so that the channels could be cleared of extra material and residue before being capped. Another modification included adding a "neck" to the outlet channel, which has helped with droplet formation in past experiments [7]. An image of the modified Angled Junction Version 3 chip can be found below.

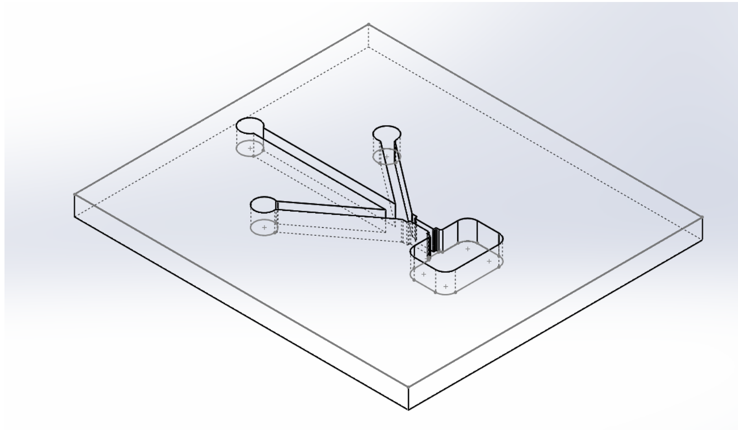

Figure 5.1.8a: Glass cap compatible chip.

Issues with using the glass cap include some difficulty in fabricating the glass chip (requiring a dremel tool to fabricate the necessary inlet and outlet holes) and securing the glass to the top of the NinjaFlex. Developing a seal between the NinjaFlex and the glass cap was accomplished using a small clamp. Both chips were printed with the following print settings.

Printing Parameter	**Value**
i	95%
T_e	250 C
v_t	200 mm/s
v_e	10 mm/s
h	.1 mm

Table 5.1.8b: MakerBot Printer parameters for final chip design prints.

6. DATA AND RESULTS: DROPLET EMULSIFICATION

6.1 Angled Junction Version 3 Results

The first chip tested for droplet emulsification capabilities was the Angled Junction Version 3 chip. Water (mixed with green food dye) was first pumped through the water inlet to ensure the channel was open. Fortunately, it seemed that the channel was open, as the microchannel quickly became stained green. However, the bond between the NinjaFlex and the glass was extremely poor. Water began to leak throughout the chip, and eventually, the chip separated from the glass substrate. This trial was deemed a failure in that no droplet emulsification was observed, and flow through the micro channels was only observed briefly. Images of this trial are shown in the figures below.

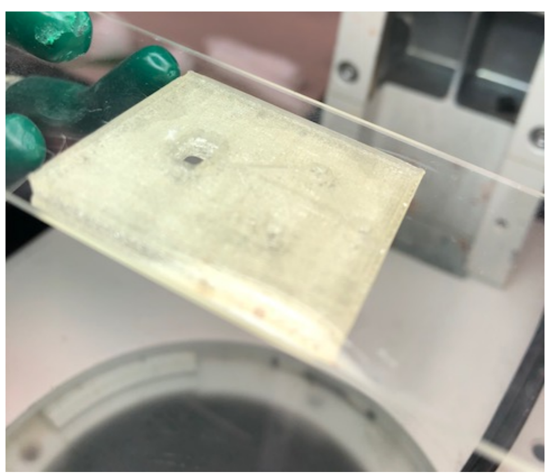

Figure 6.1.1: Test chip secured in apparatus.

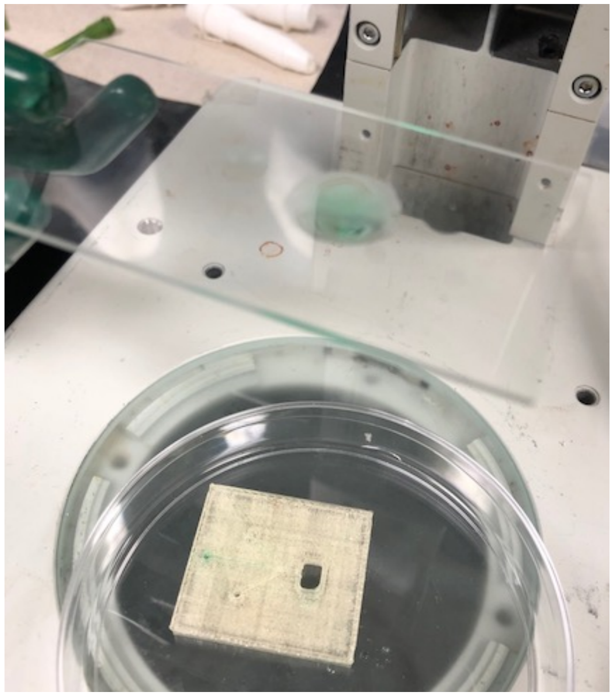

Figure 6.1.2: Microchip completely separated from glass substrate.

Because the bonding failure between the glass and the NinjaFlex occurred, the glass capped chip was not tested. It was assumed that the same mode of failure would occur with this design. Along with that, the chip is expected to contain the fluid within the micro channels (which it did not do).

6.2 Replacing glass substrate with NinjaFlex base

Because it was apparent that the NinjaFlex was not going to bind to the glass sufficiently to seal the micro channels, the part was modified to include a 0.3 mm base made of NinjaFlex. Fortunately, when printed in such a thin layer, NinjaFlex is almost completely transparent. This would make viewing the channels possible, even without a glass cap. An image of the part is given below.

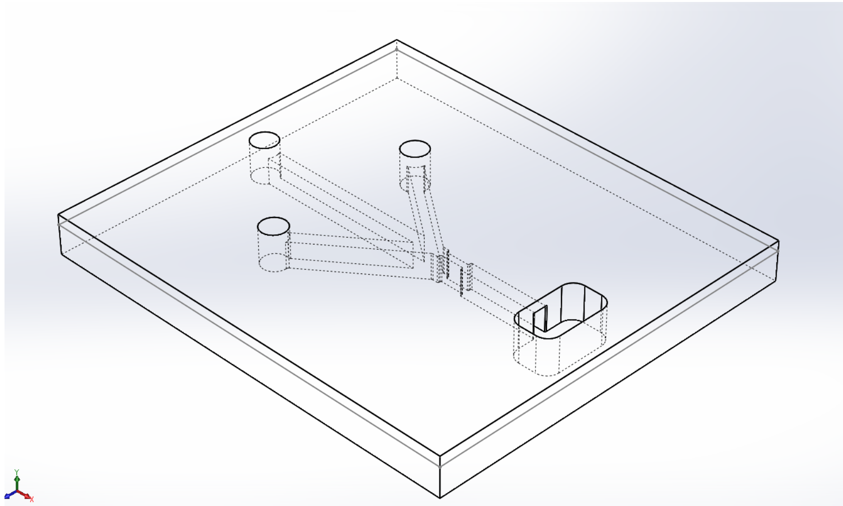

Figure 6.2.1: Microchip design including 0.3 mm thick base layer.

The testing with this chip began by ensuring that all of the micro channels were open. This was done by running water (dyed green) through the channels and noting any locations where the dye was not present. An image of the chip before and after the test is shown below

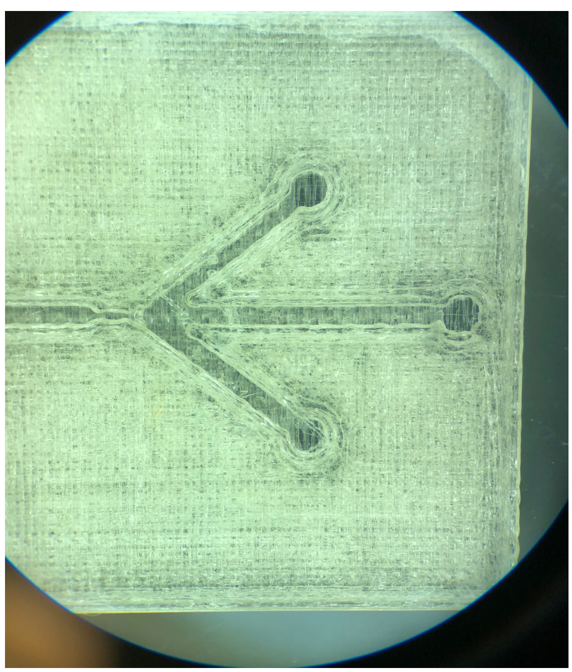

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Figure 6.2.2: Microchip before dye testing.

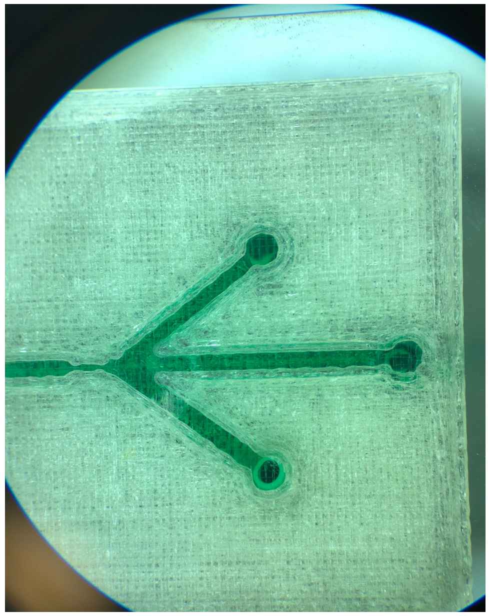

Figure 6.2.3: Microchip after dye testing.

As can be seen, all channels appear to be open from the dye test. From here, droplet emulsification capability testing was conducted. The testing was accomplished by directly following the procedure documented in section 4.3 of this report. To start, the oil side pressure was set to roughly 2.5 psig and the water side flow rate was set to 50 μL/min. A steady stream of water flowed through the outlet, but no oil was observed to separate any droplets. An image of this is given below.

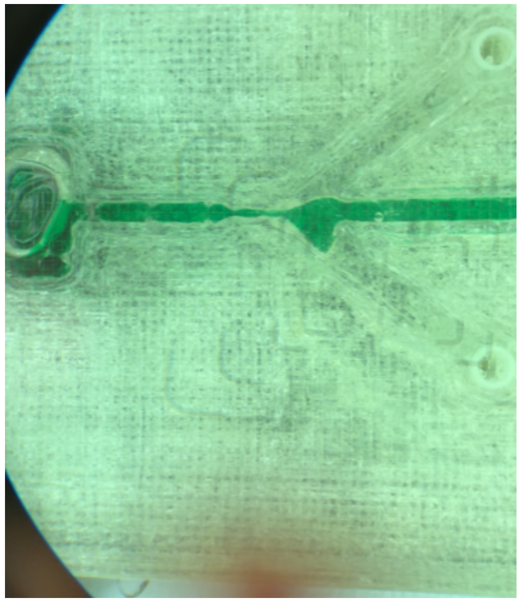

Figure 6.2.4: Flow through chip with oil side pressure at 2.5 psig and water flow rate at 50 μL/min.

After this observation, the water flow rate was brought down to 25 μL/min while the oil side pressure was kept the same. With this configuration, consistently sized droplets were generated at a regular time interval. A figure of this droplet formation is given below.

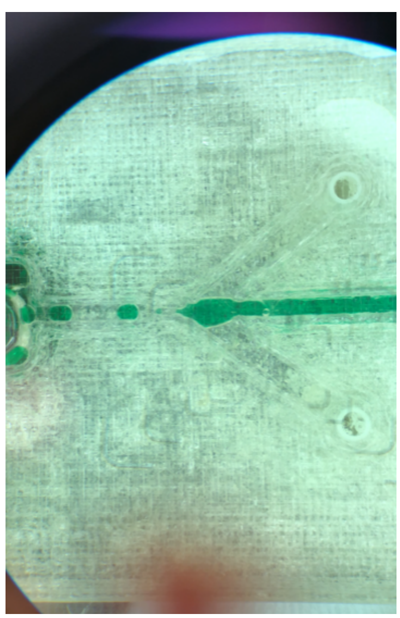

Figure 6.2.5: Droplet formation on the left at oil side pressure of 2.5 psig and water flow rate of 25 μL/min.

7. FUTURE RESEARCH

There are various ways that this final design of the microchip could be improved. First of all, the diameter of the channels could be decreased to reduce the size of the droplets. However, the channels cannot be made so small that they become blocked. Also, diaphragms could be implemented on either side of the outlet channel. By actuating these diaphragms, the microchannel size can be changed and, consequently, the size of the droplets could be accurately controlled. The chip could be made thicker to allow the tube connectors to have more surface to grab onto.

The overall design of the experiment could also be improved. Generating the oil flow rate would be better accomplished using a syringe pump rather than using the nitrogen tank as a pressure source. Since not much pressure is needed to pump the oil, the nitrogen tank is not accurate enough to produce a reliable and consistent oil flow rate.

8. CONCLUSIONS

- With a sufficient design, 3D printing NinjaFlex is a reliable way to create a microfluidic chip capable of droplet emulsion.
- The bond between NinjaFlex and glass is not reliable for sealing micro channels.
- Optimal print settings for NinjaFlex for applications in microfluidics can be seen in Table 5.1.8b.
- For this specific chip design, oil side pressure of 2.5 psig and water flow rate of 25 μL/min produces same sized droplets at a consistent time interval.

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APPENDIX

A1. Equipment Details

- MakerBot Replicator 2 3D printer
  - Make: MakerBot
  - Model: Replicator 2
  - S/N: NA
  - Location: UARK ENRC
- SolidWorks
  - Make: NA
  - Model: NA
  - S/N: NA
  - Location: UARK MEEG
- NinjaFlex printing material

- Make: NA
  - Model: 1.75 mm diameter
  - S/N: NA
  - Location: UARK ENRC
- Glass chip
  - Make: Electron Microscopy Sciences
  - Model: Unknown
  - S/N: NA
  - Location: UARK ENRC
- MakerBot Print software
  - Make: NA
  - Model: NA
  - S/N: NA
  - Location: Available for download
- Microscope
  - Make: Litemite
  - Model: 9 series circular illuminator
  - S/N: NA
  - Location: UARK ENRC
- Syringe Pump
  - Make: Harvard Apparatus
  - Model: NA
  - S/N: B15159
  - Location: UARK ENRC
- Z-axis adjustable support stand
  - Make: NA
  - Model: NA
  - S/N: NA
  - Location: UARK ENRC
- 1/8 in. inner diameter tubing (2 ft)
  - Make: Tygon
  - Model: Application Specific Tubing
  - S/N: NA
  - Location: UARK ENRC
- 1/32 in. inner diameter tubing (4 ft)
  - Make: Tygon
  - Model: S-50 HL
  - S/N: NA
  - Location: UARK ENRC
- Micro piping connectors
  - Make: Nordson Medical
  - Model: Straight Through Tube Fitting with Classic Series Barbs, 1.6mm ID
  - S/N: NA
  - Location: UARK ENRC
- Micro T junction

- Make: NA
- Model: NA
- S/N: NA
- Location: UARK ENRC

- Nitrogen tank (pressure source)
  - Supplier: Airgas Mid South
  - Model: NA
  - S/N: NA
  - Location: UARK ENRC
- 3 mL syringe
  - Make: BD
  - Model: 3ml syrginge Luer-Lok Tip
  - S/N: NA
  - Location: UARK ENRC
- 30cc syringe
  - Make: NA
  - Model: NA
  - S/N: NA
  - Location: UARK ENRC
- Syringe nozzle (1.6 mm ID)
  - Make: NA
  - Model: NA
  - S/N: NA
  - Location: UARK ENRC